CONCLUSIONS

In conclusion it may be said that the balance of evidence appears to support, but does not prove, the following statements:

1. The temperatures recorded by the Fergusson sounding balloon meteorograph up to altitudes at least as great as 26 or 28 km. are effected very little by insolation. By "very little" is meant not more than 5°C. error at 26 km. and in all probability the error is not greater than 1°C. or so. The best evidence of this is the comparison between Fergusson and Jaumotte meteorograph records, and the Fergusson meteorograph descent records of which figure 5 is an example.

2. Since the effect of insolation is small there must be an appreciable diurnal variation of temperature at all levels up to at least 26 km.

3. The day to day temperature changes at 24 km., or so, and higher are in the same direction as the changes at the ground on clear days. This is probably made possible by a changing composition with elevation in the upper levels.

4. On account of lag the recorded temperatures in the high level inversion may actually be lower than the true values instead of too high.

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THE DUAL RAINFALL REGIME OF ROSWELL, NEW MEXICO

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INTRODUCTION

Current methods of studying the seasonal incidence of rainfall at any particular station are practically all based upon the fundamental assumption that there exists at that station some sort of normal regime of which each annual record is a variant. Though it may be conceded that such variations are of great magnitude, they are usually regarded as wholly fortuitous in character and are expected to cancel each other out in the long run. A record for some 35 consecutive years is usually regarded as sufficient to effect this process, and indeed, in many parts of the world, climatologists count themselves fortunate if the body of data at their disposal is not considerably less comprehensive than this.

Strictly speaking, the distinction between record and normal should be threefold, for we ought not to confuse the normal-as-calculated with the true normal which is no more than a hypothesis. Let us briefly review each of these aspects to make sure that their essential character is not misunderstood.

1. The *annual record* in the case of precipitation data is usually presented as a series of 12 monthly totals. The employment of arbitrary and unequal calendar months instead of more uniform intervals, such as lunar months, is certainly to be regretted but to make a change now would necessitate the conversion of all past records, a thankless and, in many cases, impossible task. The important point is that daily records, even when available, *must* be grouped together to include a considerable time-span before any signs of the emergence of a regime will become apparent. The imperative nature of this consideration is often overlooked although it is no more than an expression of our daily experience of the weather.

Evidence exists that in monsoon lands the necessary period should be more than a week, in Great Britain and New England it is probable that even the calendar month is scarcely adequate for the purpose. There is no mystery about this, it is simply a reflection of the fact that in tropical lands the weather may be expected to take some anticipated course with a greater degree of punctuality than is the case in more temperate latitudes. If we wish to register that tempo with maximum efficiency, we must make adjustments of the time factor accordingly.

It is well that this should be recognised even if the presentation of published data makes use of the 12 monthly totals virtually inescapable.

2. *Mean monthly values* are also frequently published but they are referred to in varying terms. In the "Climatic Survey of the United States" they are called "averages"; in "World Weather Records" they are known as "means"; whilst in publications of the British Meteorological Office they become "normals." In view of the fact that all of these are computed by the same identical method of striking an arithmetical average, this diversity of expression is unfortunate. In the rest of this paper the term "average" alone will be used in this connection.

Elsewhere it has been shown that published averages are not always the best descriptive means for use in connection with rainfall data (1). Reasons have been given for regarding median values as a closer approximation to normality. But, although some acquaintance with that discussion is necessary to an understanding of the methods of analysis which follow, the present argument does not hinge upon this distinction.

3. Whilst the record is the direct product of observation and the mean is the tool of the practical climatologist, the *true normal* is no more than an hypothesis, a

mental image. From the traditional point of view it is the *limit* to which the average will tend as the record is extended over an indefinitely increasing number of years. The question how long a period is required to give the average a certain degree of working validity is thus one involving the mathematical theory of sampling and is not solved merely by covering a single Brückner cycle.

This aspect of the matter has been viewed with relative unconcern by climatologists since they are compelled willy-nilly to employ the body of somewhat fragmentary and almost certainly inadequate information at present to hand. But the concept of a single true normal may be challenged upon another count. It is the object of this paper to attempt to show that, in transitional areas at least, there may be two alternative normals. If this is true,the use of a single series of mean values represents the arithmetical fusion of two tendencies which actually remain distinct in nature.

The test case is that of Roswell, N. Mex., where it has been shown in an earlier paper (1) that the rainfall regime is transitional in character between the two striking types experienced on the Plateau of New Mexico in the west and in the Plains of Texas in the east. Our object is thus to demonstrate that at Roswell itself, these two regimes *alternate but do not fuse.* If a prima facie case is made out in favor of this view, the matter is unlikely to rest there. Climatic transitions are found all over the world and elaboration and development of the present method may help us to attain a deeper perception of climatic facts in many unexpected places.

SELECTION OF YEARS

The problem that poses itself is how to disentangel the two themes which are regarded as running through such a record. How can we separate out the "Plains" from the "Plateau" years at Roswell? If the record could be resolved into *two* means it might be possible to carry conviction but any attempt to split it for this purpose really involves a complete reversal of the usual roles played by record and average. Hitherto the average has been employed to eliminate chance variations; it has been a yardstick against which "departures" of the actual record have been assessed. It is now suggested that the record should be used to check the general average and by a process of selection from it we hope to reduce that average to the elements of which it is composed.

Clearly such an approach must encounter two difficulties of the first magnitude. On the one hand, the records for individual years vary so widely with the play of chance that rigid and objective criteria of selection may be very hard to apply to them; and on the other, the averages for the two groups will certainly bear the stamp of any subjective element of distinction that creeps into the process. Careful safeguards must therefore be devised if truly significant contrasts are to be clearly distinguished from purely accidental differences. Indeed, the method must always be used with the greatest caution but a deliberate selection of years for comparison is unavoidable. The precautions against freak results that have been taken in the following discussion are as follows:

1. Selection of years has been made upon certain definite criteria and care is taken that, in interpreting results, it is not these very features that are employed.

2. Control stations are used to indicate how far that characteristic is itself the result of the selection rather than of any real difference in the nature of the record.

3. In summing up the two groups a measure of the scatter about the mean is consistently employed along

with it. This is most rapidly done by using a dispersion diagram.

4. In interpreting the resulting curves only those features which have some logical significance, that is, features recalling either one side or the other of the transitional belt, are given much attention.

The record selected for subjection to this mode of analysis is that for Roswell, N. Mex., over the 44 years from 1895 to 1938, inclusive. Records of this length beyond the borders of the transitional belt are available at San Marcial, about 150 miles westwards, and Crosbyton, some 175 miles to the east. Although these distances seem considerable it must be remembered that a hundred miles does not count for much in the open plains of western America.

Seventy to eighty miles south of these stations lie Carlsbad, Agricultural College, and Big Spring in corresponding locations. (2) San Marcial and Agricultural College were placed in the "Rio Grande Region" in an earlier classification of rainfall types, whilst Crosbyton and Big Spring fell into the "Canadian River Region," but for present purposes it will suffice to refer to the two regimes as the "Plateau" and "Plains" types respectively. A glance at diagrams (c) in figures 2, 5, 4, and 7 will make the contrast between these abundantly clear. In the Plateau type the first 6 months of the year are virtually rainless and the rains occur mainly during July, August, and September. In the Plains type the rain period is of 7 months' duration from April to October, inclusive, and over most of this interval there is little to choose between one month and another. Clearly the transition zone between such contrasts should be of particular interest—it is represented by Roswell and Carlsbad. Our object is thus to try and recognise Plains type and Plateau type years at Roswell and to check the distinction by applying it to each of the other five stations.

An obvious first step is to present the Roswell record as an historical sequence. This is done in figure 1 where similar graphs for San Marcial and Crosbyton also appear. To simplify the graphs a little the figures have been plotted as 2-monthly totals, January plus February, March plus April, and so on. This method of grouping should not obscure any important feature of the curves (3).

Viewing each graph as a whole we are first impressed by the range of variation from year to year. Even at San Marcial, where the normal regime seemed extremely clearcut, the variety of annual forms is astonishing. Although, according to average values, the second half of the year should obtain about three times as much rain as the first, there are actually three cases where the first half of the year is the wetter and in four or five others the position is not far from equality. Our acceptance of the concept of normality is thus based upon the general weight of the evidence during the remaining 36 or 37 years and even in a case as striking as this one, regime is shown to have no high degree of inevitability.

A year-by-year comparison of the three graphs brings out further points of interest. In a few years all swing together—as in 1898, 1902, 1922, 1925, and 1936—sometimes with remarkable precision. On other occasions, fortuitous circumstances seem to be in the ascendant and there is little resemblance between any of them (4). But in the great majority of cases the Roswell curve is similar in outline to but one of the others and the number of instances of each would seem to be roughly equal. This is good evidence of the alternation we are seeking to establish.

A first criterion for the selection of the two groups of

years might therefore be the *general form* of the annual curve. The difficulty here is that this may be dominated by some chance event and if some of the contrasts are due to quite odd and local downpours, who shall say that some of the apparent resemblances have a firmer basis in fact? Besides, the "general form" is a vague conception and is capable of varying interpretation in different hands. We need some more specific definition of form especially when considering the inevitable residue of odd or freak

likely to revolve, and may lead to the accusation that results have been induced by the method, instead of having been developed out of it; and (3) we are still much at the mercy of freak variations in the particular months concerned—a position, it is true, which no method will allow us completely to escape.

A third method combining breadth with precision would thus seem preferable. It might well be developed out of the *comparison of half-yearly totals* like that already made
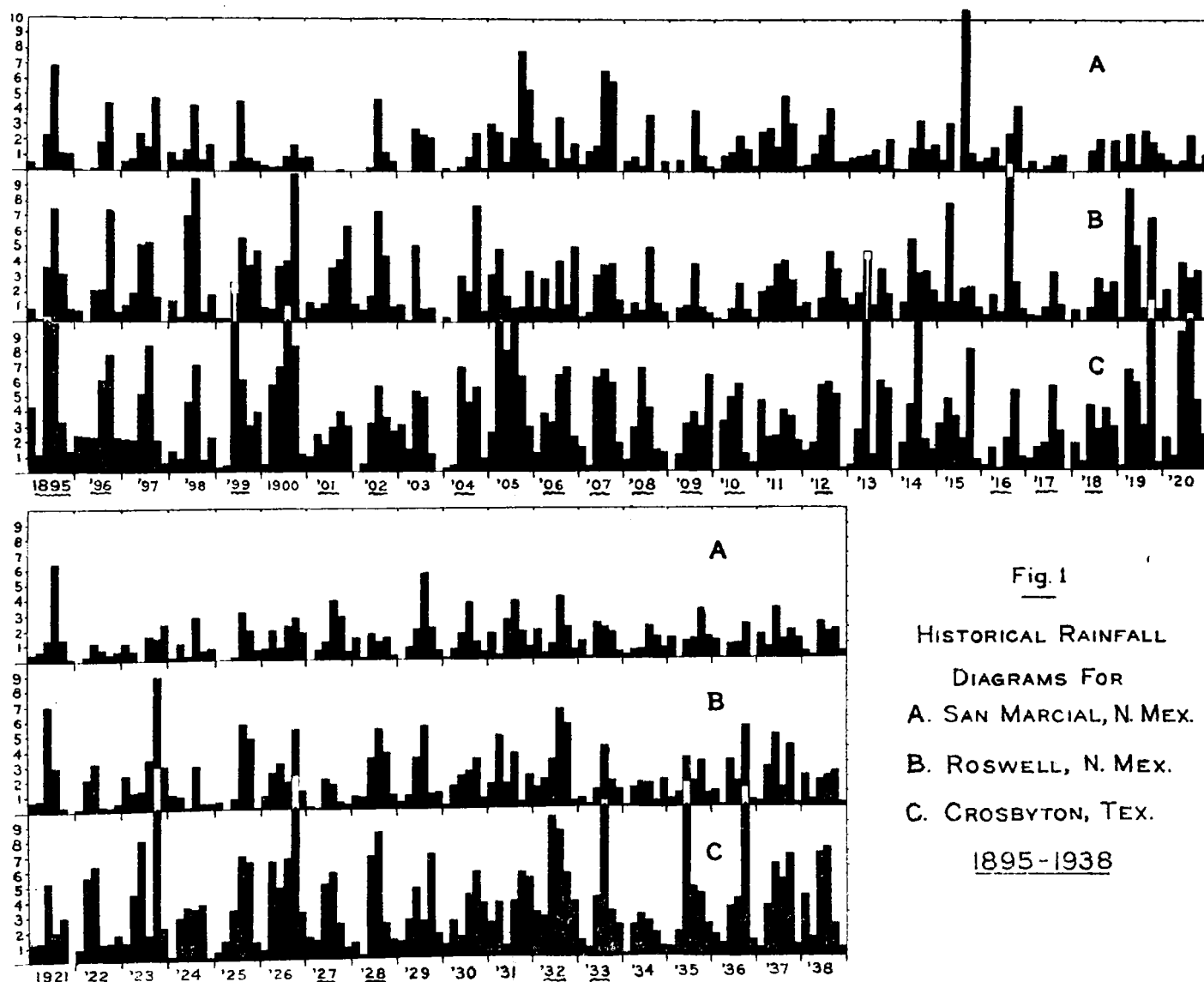

Fig. 1

HISTORICAL RAINFALL

DIAGRAMS FOR

A. SAN MARCIAL, N. MEX.

B. ROSWELL, N. MEX.

C. CROSBYTON, TEX.

1895-1938

forms, the classification of which may present great difficulty.

Greater precision may be achieved if emphasis is laid upon *key elements* in the form of the regime curve. Thus the Plateau type may be characterised by the vigorous rise from June to July, or from May to July. Similarly the Plains type may be recognised by the rise from March to May. Years displaying either of these features would thus be classified accordingly, regardless of the course of events at other times. This method certainly has a high degree of objectivity and is a logical development of emphasis upon rainfall "breaks" or "discontinuities" but it also encounters difficulties: (1) It uses but a fraction of the information at hand; (2) that fraction contains the very points upon which our subsequent argument is

in discussing the historical diagram for San Marcial. In this manner the selection is freed in large measure from the difficulties attendant upon monthly variation and yet the comparison of monthly means when the two groups have been summed up is not invalidated. The necessary data for Roswell are given in table 1 along with similar figures for San Marcial and Crosbyton.

The actual method of selection employed below has been compound in character but it leans heavily upon table 1. Alternative criteria have been compared and combined to reinforce our case but any one of them taken alone would seem to provide a fairly reasonable basis for distinction.

In the first place, it is argued that Plateau type years at Roswell should have little rain during the first 6 months.

TABLE 1.—*Half-yearly rainfall at San Marcial, Roswell, and Crosbyton*

Year	San Marcial		Roswell		Crosbyton	
	January–June	July–December	January–June	July–December	January–June	July–December
1895	2.92	9.16	4.63	11.51	15.90	14.60
1896	0.19	6.36	2.85	10.27	7.10	16.20
1897	3.77	6.36	8.22	7.01	9.50	11.10
1898	3.32	6.76	8.88	12.08	7.00	10.20
1899	0.72	6.06	2.39	14.17	13.40	13.30
1900	0.88	3.51	5.60	14.20	13.30	20.70
1901	0.93	0.15	3.59	14.55	5.30	10.10
1902	0.27	6.56	3.80	12.78	3.80	12.30
1903	2.90	4.67	6.39	1.78	10.10	6.20
1904	0.50	3.66	3.47	10.58	7.60	11.30
1905	6.26	15.53	9.78	5.45	20.90	19.36
1906	2.95	6.28	4.82	10.39	8.44	15.79
1907	3.46	12.60	4.18	9.25	8.35	14.73
1908	2.10	4.36	2.59	7.03	10.63	6.98
1909	0.81	5.41	2.11	5.58	4.37	13.43
1910	2.57	4.26	1.24	3.63	8.30	7.50
1911	7.15	8.51	8.34	8.03	9.37	9.74
1912	4.06	5.42	3.09	9.81	8.89	11.33
1913	2.94	3.95	7.30	6.47	17.88	12.59
1914	1.83	6.55	6.65	8.80	6.34	13.60
1915	3.91	12.46	10.55	5.62	11.60	11.01
1916	2.86	7.07	2.74	14.08	1.97	8.41
1917	1.15	2.10	1.71	4.50	4.10	8.40
1918	1.45	4.17	1.70	7.48	6.76	9.81
1919	3.56	5.76	14.08	8.61	12.85	15.05
1920	1.80	3.81	6.09	6.49	12.32	17.51
1921	2.43	8.03	8.46	3.21	7.79	4.96
1922	1.54	1.64	5.48	1.09	12.85	4.20
1923	1.81	5.39	4.85	15.19	13.70	16.86
1924	1.58	4.14	2.05	3.72	6.60	7.37
1925	0.18	5.61	1.18	10.35	5.09	14.54
1926	3.38	6.93	6.37	8.42	11.84	22.12
1927	1.78	7.31	2.31	2.52	7.77	8.93
1928	3.19	2.88	5.01	10.03	8.09	11.95
1929	2.88	8.41	4.74	7.64	8.30	11.11
1930	2.46	5.52	3.95	6.52	4.87	13.68
1931	4.66	6.64	8.16	6.26	6.73	14.61
1932	3.29	6.74	6.39	12.44	15.00	17.66
1933	3.68	4.21	1.83	6.96	5.81	15.71
1934	1.19	4.31	3.03	3.93	5.14	4.70
1935	2.41	5.95	4.88	5.66	13.84	11.53
1936	2.02	3.22	4.30	7.52	5.77	16.12
1937	5.70	4.45	7.79	5.66	10.17	12.69
1938	3.05	4.10	4.37	4.71	12.21	10.12

The *absolute* values in the first columns of table 1 have therefore been surveyed and the twenty-two years when these were least are given in column (1) of table 4. This makes a good provisional classification but its weakness is that it uses but half of the information at hand.

It may well be argued that it is the low *proportion* of the annual rainfall falling during the first 6 months that should be stressed. The relationship is therefore stated as a percentage in table 2 from which the years with lowest values are easily extracted for column (2) of table 4.

TABLE 2.—*Roswell, N. Mex., percentage of annual rainfall falling in first half of year*

Year	Percent	Year	Percent
1895	29	1917	28
1896	22	1918	18
1897	54	1919	62
1898	42	1920	48
1899	14	1921	72
1900	28	1922	83
1901	20	1923	24
1902	23	1924	35
1903	78	1925	10
1904	25	1926	43
1905	51	1927	48
1906	32	1928	33
1907	31	1929	38
1908	27	1930	38
1909	27	1931	56
1910	25	1932	34
1911	51	1933	21
1912	24	1934	43
1913	53	1935	46
1914	43	1936	36
1915	65	1937	58
1916	16	1938	48

Comparing the 2 series of results we now find that they agree in 17 cases and these years at Roswell may be declared provisionally to have had a regime not dissimilar from that of the Plateau type. The question now arises whether or not an attempt should be made to

add another 5 years to this group so as to split the record equally. Theoretically it is a moot point, since the vibrations of a fluctuating border will only yield equal frequencies along a narrow central zone which cannot be predetermined. On practical grounds, on the other hand, there is much to be said for equal division, for it simplifies questions regarding the validity of means, the disposal of doubtful cases, and the rebuttal of charges of begging the question. Much will depend upon what judgments may be arrived at regarding the doubtful group.

TABLE 3.—*Roswell, N. Mex., comparison of May–June with July–August rainfalls*

Year	May–June	July–August	Percent increase	Year	May–June	July–August	Percent increase
1895	3.59	7.44	107	1917	0.97	3.32	243
1896	2.09	2.19	5	1918	0.88	2.87	226
1897	5.18	5.32	3	1919	5.02	0.87	------
1898	7.08	9.52	35	1920	3.93	2.88	------
1899	1.89	5.58	195	1921	7.07	2.95	------
1900	3.75	4.10	9	1922	3.19	0.32	------
1901	1.26	3.68	189	1923	1.28	3.37	164
1902	1.73	7.32	323	1924	0.15	2.88	1,820
1903	5.11	0.86	------	1925	0.70	5.60	700
1904	3.10	2.06	------	1926	3.04	1.84	------
1905	1.79	0.98	------	1927	2.04	1.67	------
1906	0.88	4.13	370	1928	3.45	5.31	54
1907	3.18	3.80	19	1929	3.45	5.55	61
1908	0.75	5.03	570	1930	2.20	2.52	15
1909	1.10	3.95	259	1931	1.63	3.69	126
1910	0.90	2.60	189	1932	3.20	6.58	106
1911	3.83	4.16	9	1933	1.13	4.07	260
1912	1.55	4.74	206	1934	1.69	1.61	------
1913	4.20	1.10	------	1935	3.33	1.74	------
1914	5.22	3.30	------	1936	3.15	1.64	------
1915	1.32	2.22	68	1937	4.79	1.27	------
1916	0.61	10.60	1,637	1938	1.79	2.04	18

TABLE 4.—*"Plateau type" years at Roswell according to different criteria*

(1)	(2)	(3)	Points	Years used (Group A)
1895	1895	1895	3	1895
1896	*1896*		3	1896
		1898	1	
1899	*1899*	1899	5	1899
	1900		1	
1901	*1901*	1901	4	1901
1902	*1902*	*1902*	5	1902
1904	*1904*		3	1904
	1906	*1906*	3	1906
1907	1907		2	1907
1908	1908	*1908*	5	1908
1909	1909	*1909*	5	1909
1910	1910	1910	4	1910
1912	*1912*	*1912*	5	1912
		1915	1	
1916	*1916*	*1916*	6	1916
1917	1917	*1917*	5	1917
1918	*1918*	*1918*	6	1918
	1923	1923	3	1923
1924	1924	*1924*	5	1924
1925	*1925*	*1925*	6	1925
1927			2	1927
	1928	1928	2	1928
		1929	1	
1930			1	
		1931	1	
1933	1932	1932	2	*1932*
	1933	*1933*	6	1933
1934				
1936				
1938				

NOTE.—In each column the eleven most extreme cases have been *italicized*. In the final assessment each of these is given two points.

A third method of selection has therefore been added. It is based upon a modified interpretation of the concept of the key element of the Plateau regime discussed above, namely, upon the proportionate difference between the fall of July plus August as compared with that of the previous two months. The data are given in table 3 and the resulting group of years appears in column (3) of table 4.

Interpreting this table as a whole we note that fourteen years appear in each of the three columns. These should form the hard core of the Plateau group (Group A). Conversely, thirteen years find no mention in any of the columns and are thus probably the most important element of the Plains group (Group B). The remaining doubtful cases would seem at first to set rather a difficult problem (5) but if years with any two of the three qualifications are accepted in Group A this at once includes 21 instances. A very simple system of weighting suggests that 1927 is the year required to complete the equal division. Weighting, in order to distinguish still more clearly between established and doubtful cases would

no more than two aspects of a basically homogeneous body of data. Our broad methods of selection ought not to debar us from comparing individual months in the two graphs. Notice then that the upper quartile for May in group (a) barely reaches the lower quartile for that month in group (b). The June-July "break" and the more abrupt May-July contrast, both so characteristic of the Rio Grande region, are thus clearly in evidence in the one diagram and completely absent from the other.

The essence of a diagrammatic method, however, lies in its value for *comparative* purposes. We therefore also present figures 2 and 4 where the same grouping of years has been applied to the data for two stations lying outside

SAN MARCIAL, NEW MEXICO

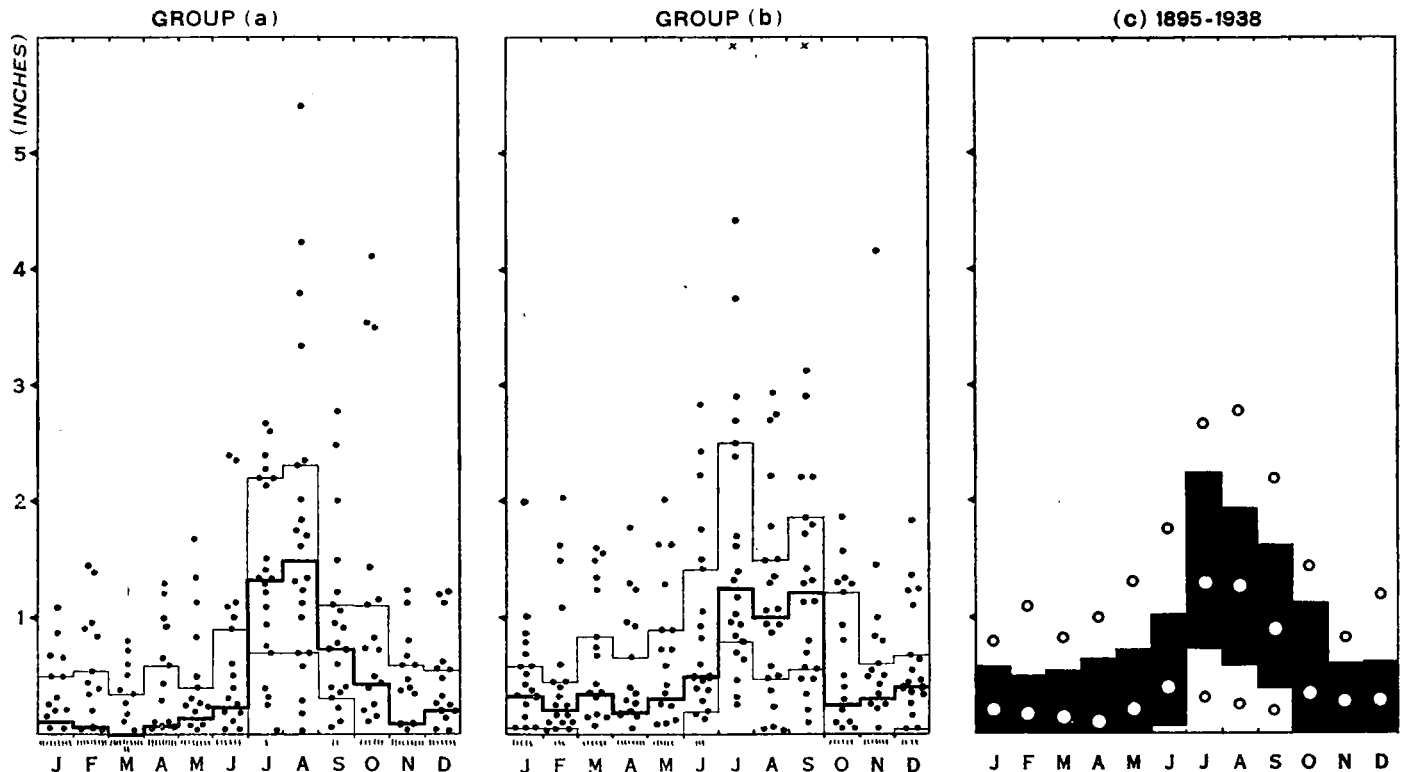

FIGURE 2.

also be a wise precaution should a student try to correlate our results with those yielded by some other element of climate.

DIAGRAMMATIC PRESENTATION OF THE TWO GROUPS

Selection now being complete, it remains to show that the two groups of years at Roswell have indeed contrasting characteristics of a degree at all comparable with those of the Plateau and Plains regimes we have been discussing. This may be done by striking a series of monthly averages for each group or by plotting both of them on separate dispersion diagrams. Figure 3 represents the results of the latter method.

Interpretation of these diagrams depends upon reasonable probability and is therefore not capable of great precision. The quartile range is never more than a rough index of scattering and its efficacy as a test of significant change is substantially reduced when a record is halved. Nevertheless, the contrasts between diagrams (a) and (b) are so great that it seems highly improbable that they are

the transition zone. Theoretically, the regimes at these stations should have but a single theme and our method of grouping ought not to produce significantly different results. This reasoning finds substantial confirmation in the facts. Subsidiary differences do occur, and may be followed up when the implications of this method are better understood, but the characteristic features of the Plateau regime are found in both diagrams of figure 2 and on neither of those of figure 4. It thus seems reasonably certain that the contrasts between groups (a) and (b) at Roswell were not primarily due to our methods of selection.

Yet a further test is to apply precisely the same grouping to the records for Agricultural College, Carlsbad, and Big Spring. (See figs. 5-7.) In view of the fact that the selection of years was based upon none of these records, the results cannot be regarded as disappointing. There is the same great contrast between the May values in the two groups at Carlsbad whilst the essentially homogeneous character of the records at Agricultural College and Big Spring is clearly demonstrated.
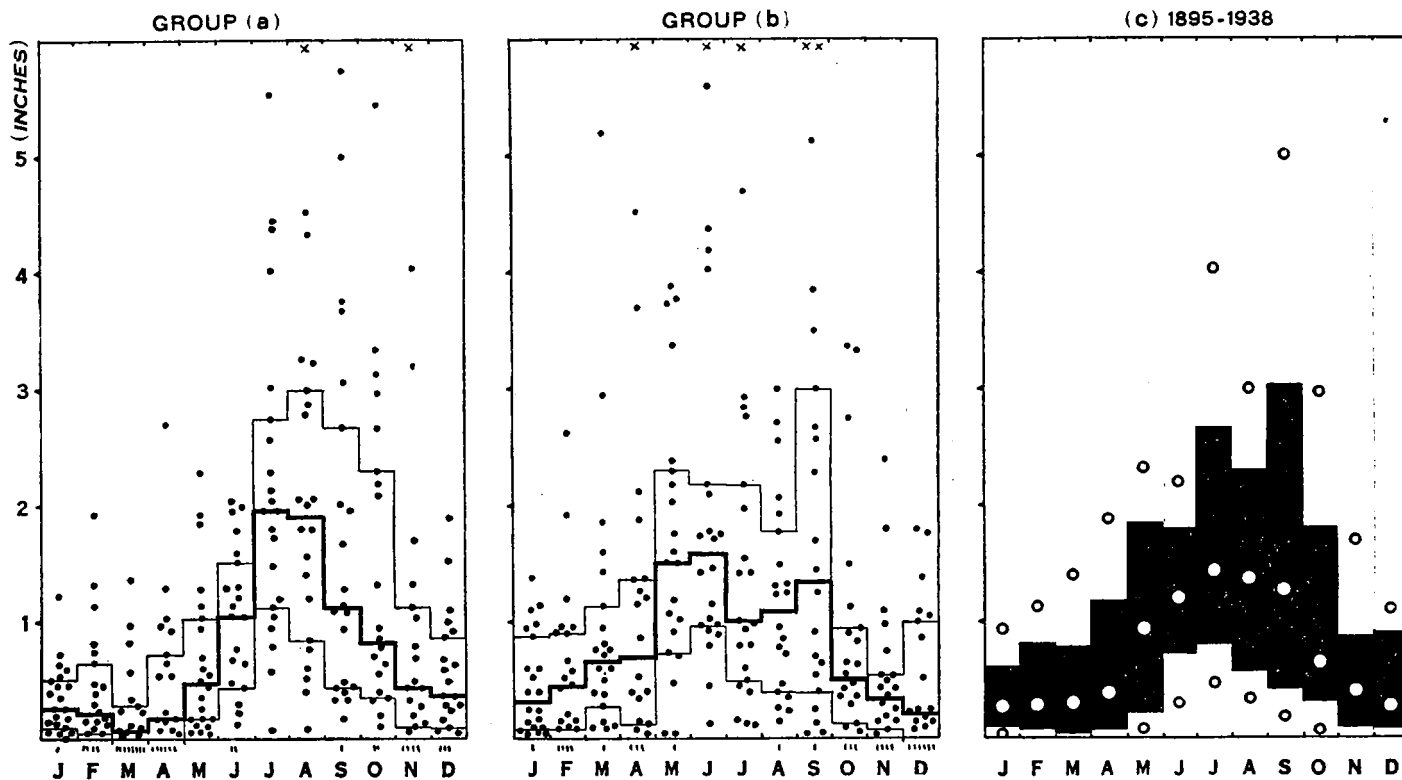
ROSWELL, NEW MEXICO

FIGURE 3.

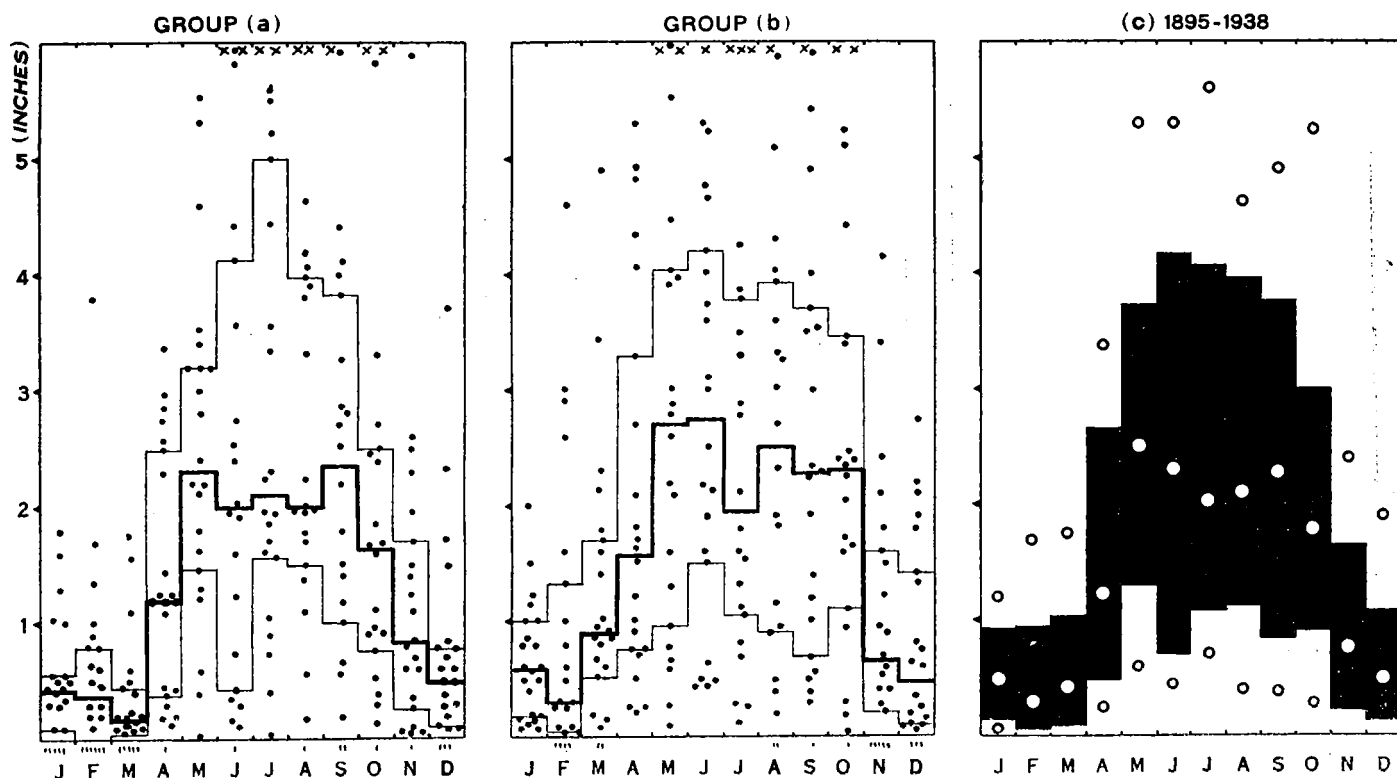## CROSBYTON, TEXAS

FIGURE 4.

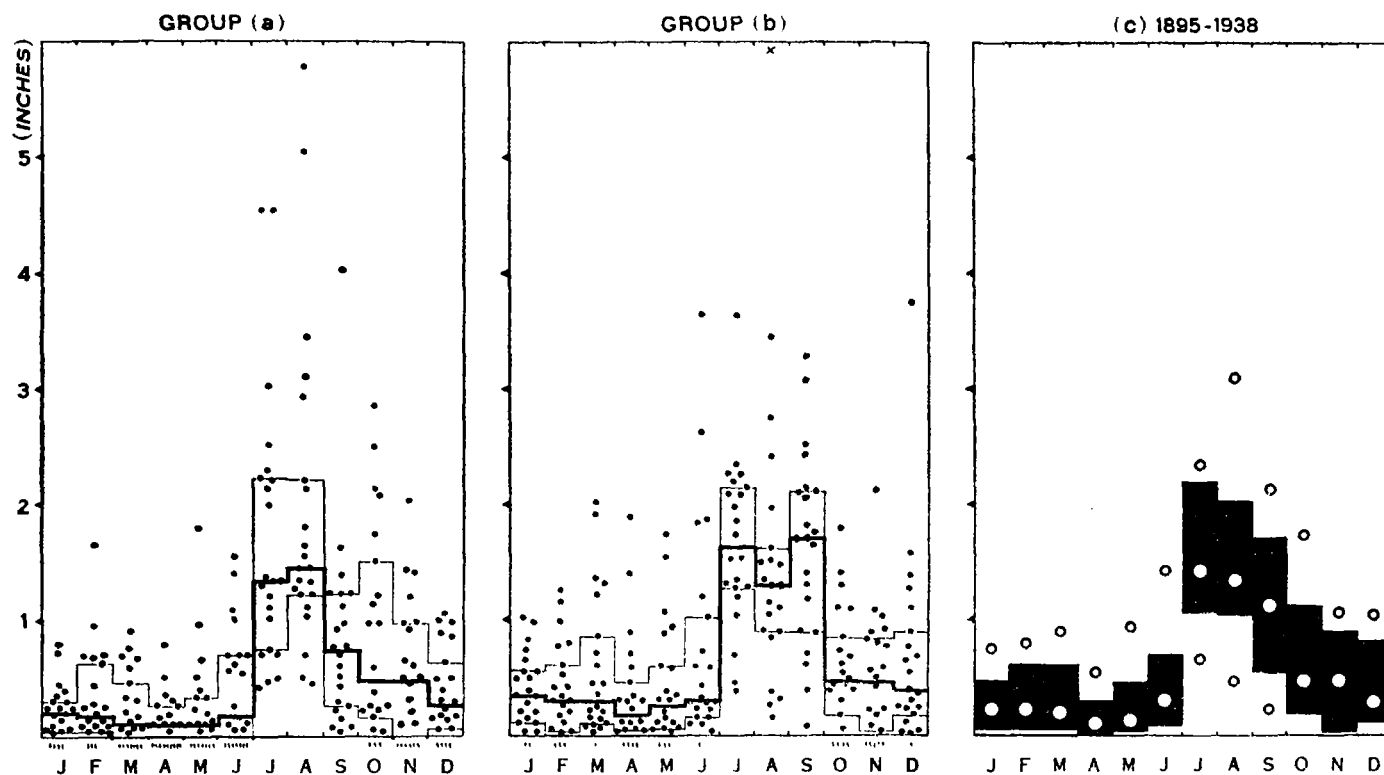## AGRICULTURAL COLLEGE, DONA ANA CITY, NEW MEXICO
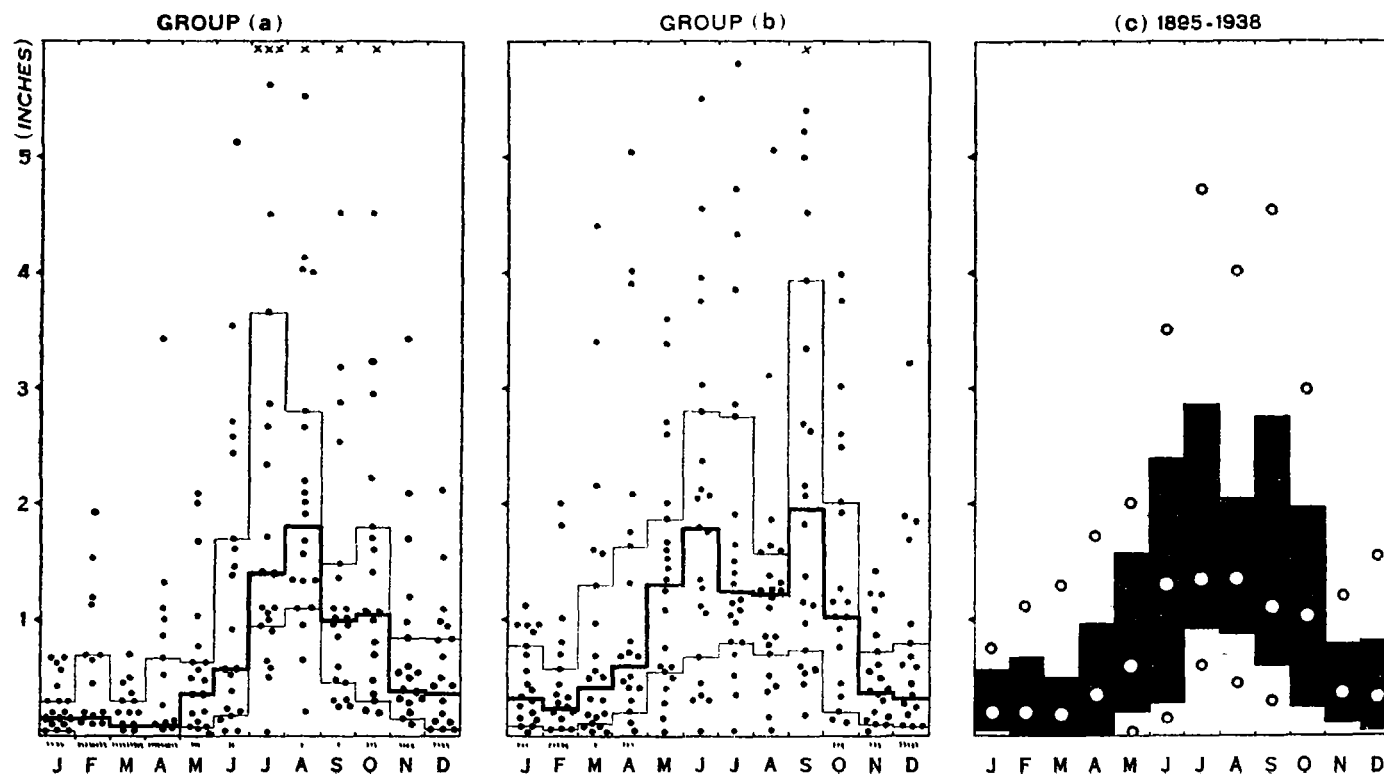

FIGURE 5.

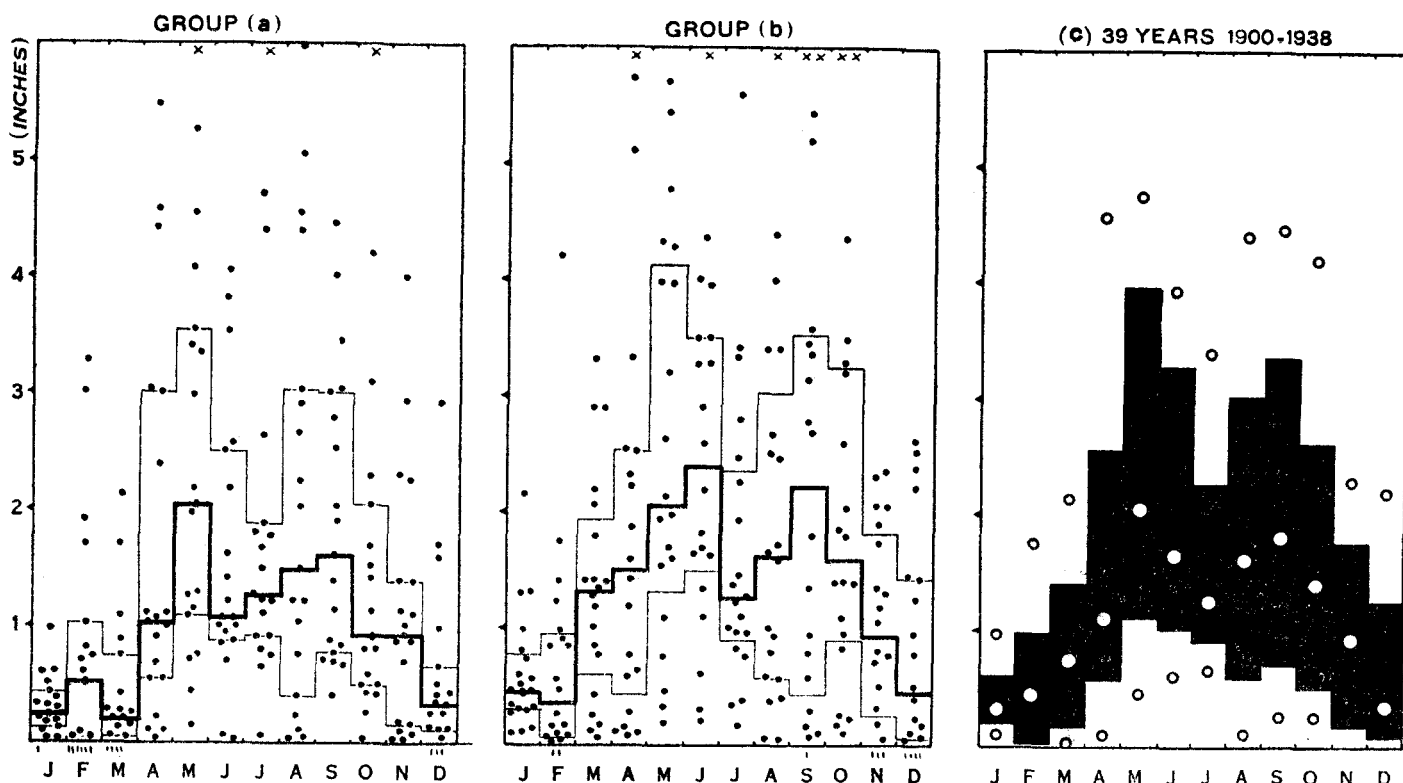## CARLSBAD, NEW MEXICO

FIGURE 6.

BIG SPRING, TEXAS

FIGURE 7.

CONCLUSION

We have thus made out the required prima facie case for the existence of a "dual" or "alternating" rainfall regime at Roswell and Carlsbad, New Mexico, and have indicated the lines along which similar comparisons might be instituted for stations in other parts of the world.

The theoretical interest of the conclusion lies both in its implications regarding the concept of "normality," and in the light thrown upon the nature of rainfall transitions. The border between what we have called the Plains and Plateau types of regime is not an amorphous fringe some 250 miles in width, such as the analysis of means would seem to indicate. In any particular year its width is very materially less than this but it is a front which swings widely from year to year. As the records for stations between those used above become long enough to be of value, further information regarding the nature of this front and its migrations should come to hand.

On the practical side it is to be noticed that there is no indication of a regular cycle of years. Forecasting the type of rainfall year to be anticipated will amost certainly

involve an understanding of the mechanisms which are operating to produce it (6). The key to successful forecast may therefore lie, not in the study of rainfall data, but in analysis of one of the other climatological elements. Our present task has been to present the facts and state the problem.

NOTES AND REFERENCES

1. In "Geographical Review" 1936, p. 484.
2. All of these, except Big Spring, have records extending over the full period 1895–1938. The record at Big Spring begins in 1900, i. e. it is 5 years short.
3. Since the most striking discontinuity encountered is that from June to July in the Plateau province. The contrast May–June to July–August should indeed be still more vigorous.
4. Also note that in 1916 the Roswell curve differs from both of the others although these are similar one to the other. A heavy local fall in August seems to have caused this anomaly.
5. The Roswell record of 44 years seems rather short for a three-fold division, even if this were thought advisable upon theoretical grounds.
6. Except insofar as *March* values at Roswell may be taken as giving an indication of the kind of rainfall year that is to follow. The method may thus hint at unexpected correlations. It will not establish them.

PRELIMINARY REPORT ON TORNADOES IN THE UNITED STATES DURING 1940

By J. P. KOHLER

[Weather Bureau, Washington, March 3, 1941]

The present study is based largely on the data contained in the tables entitled "Severe Local Storms" appearing in the issues of the MONTHLY WEATHER REVIEW during 1940. A final and more detailed study will appear in the *United States Meteorological Yearbook, 1940*. The figures here are substantially correct; however, it must be remembered that all are subject to change after the final study mentioned above.

The frequency of tornadoes during the year 1940 was considerably below normal, namely, 105 as against the

25-year average of 141. Table 1 shows that tornadoes occurred in 24 States, occasioned 50 deaths, injured more than 577 individuals and caused property damage estimated at $7,350,000.

Table 1 enumerates tornado frequency, deaths, injuries, and damage figures by States during the year. An examination of this table shows that the greatest number of tornadoes occurred during the months of March and April, with a total of 42 storms. The month of June ranked second in order, with 14 disturbances; and, in the months